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Effect of immediate dentine sealing on the aging lithium disilicate inlays and overlays

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A R T I C L E I N F O

Keywords:
Ceramic
Aging
Fracture strength
Immediate dentin sealing
Overlay
Inlay

A B S T R A C T

Objectives: The objectives of this study w mode and reparability of molars restor without immediate dentin sealing (IDS).
Methods: Forty extracted, sound human r Inlays without IDS; 3) Overlays with ID mm wide, 5 mm deep) and in groups 2 preparation, IDS was applied in specimen a heated composite. The restored teeth thermocycling loading (8000 cycles, 5–55 degrees C). Subsequently, the fracture strength was tested by a load to failure test at 45°. A failure analysis was performed using light- and scanning electron microscopy. The results were analyzed using two-way ANOVA and a Fisher exact test.
Results: Mean fracture load + SD (N) were: Group 1 (n = 12): 1610 ± 419; Group 2 (n = 12): 1115 ± 487; Group 3 (n = 12): 2011 ± 496; Group 4 (n = 12): 1837 ± 406. Teeth restored with an onlay were stronger than those restored with an inlay restoration ($p < .001$). Teeth with IDS were stronger overall than those without IDS ($p = .026$). The interaction between preparation type and the mode of dentin conditioning had no statistically significant influence on fracture strength ($p = .272$). Subsequently, custom hypothesis tests showed that there was no statistically significant difference in fracture strength between inlays with IDS and overlays without IDS ($p = .27$). Overlays tend to fail in a more destructive, non-reparable way ($p = .003$).
Significance: Both variables IDS and overlay preparation improve overall fracture strength. Inlays with IDS and overlays without IDS didn't differ in fracture strength. Both inlays and overlays are strong enough to withstand physiological chewing forces.

1. Introduction

Cavities can be restored by means of indirect or direct restorations. Some advantages of indirect restorations in large cavities are ease of restoring proximal contour, occlusal morphology and obtaining marginal adaptation (Manhart et al., 2004). In addition, less polymerization stress and microleakage can be expected (Dejak and Młotkowski, 2015). Disadvantages are the higher investment of time and money and the requirement of a diverging cavity, resulting in potentially more loss of healthy tooth tissue (Kuijs et al., 2006).

Preparation of a circumferential full crown is associated with the loss of a considerable amount of enamel and dentin. Respectively 50%–68% of tooth tissue would have to be removed in molars and premolars, which is considerably more compared to an overlay preparation (35–38%) (Al-Fouzan and Tashkandi, 2013). The application of less invasive preparation types (inlay or overlay), positively influences the survival of the pulp and thereby the life expectancy of the tooth (Edelhoff and Sorensen, 2002; Mjör and Odont, 2001). With the

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increased attention to minimal invasive dentistry, preparation designs have evolved that preserve more sound tissue (Edelhoff and Sorensen, 2002).

Partial indirect ceramic restorations have shown good survival rates up to 10 years (El-Mowafy and Brochu, 2002; Morimoto et al., 2016). A systematic review reported survival rates for inlay and onlays of 96% after 4,5 years and 91% after 7 years (El-Mowafy and Brochu, 2002). In another systematic review survival rates of 92–95% after 5 years and 91% after 10 years for ceramic inlay and overlays were noted (Morimoto et al., 2016). The most common clinically observed causes of failure of ceramic inlay and overlays are cohesive fracture in ceramic or fracture of the tooth, followed by recurrent caries and endodontic treatment (Morimoto et al., 2016). The failure mode and reparability, the ability of the failure to be repaired by a clinician, are of interest in an laboratory study.

Teeth restored with partial ceramic restorations are quite strong with fracture strengths comparable to those of sound, unrestored teeth (Morimoto et al., 2009; Stappert et al., 2008). However, controversy exists whether or not the extension of the cavity influences the fracture strength. This bears relevance to the clinical decision to cover the cusps, resulting in an overlay preparation (Shibata et al., 2014; Stappert et al., 2006). The amount of evidence is limited, but it is generally recommended to cover the cusps when wall thickness becomes less than 2 mm (Rocca et al., 2015). The restoration to be made should also be thick enough to prevent fracture of the restorative material itself (Rocca et al., 2015). In cusp coverage, a minimal occlusal reduction of 1,5-2 mm is necessary to protect a ceramic material like lithium disilicate against occlusal forces (Hopp and Land, 2013).

Both inlay and overlay preparations expose considerable surface areas of dentin. It is recommended to seal the freshly prepared dentin with a dentin bonding agent for enhanced adhesion (Qanungo et al., 2016; van den Breemer et al., 2017). This is also referred to as immediate dentin sealing (IDS). Due to decrease of contamination (temporary cement, bacteria etc.), the adhesion to dentin is optimized (Paul and Schaerer, 1997). The application of IDS also serves to protect the dentin and the pulp, which leads to less post-operative sensitivity (Hu and Zhu, 2010). Recently the clinical benefit of an immediate dentin sealing on survival rates was proven in a study on laminate veneers (Gresnigt et al., 2019). [...]

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distilled water at 37 °C during the time of the study. Teeth were randomly assigned to one of four groups (Fig. 1).

2.2. Specimen preparation

Before tooth preparation a putty impression (Silaputty, Dentasil,

Table 1
The brands, types, chemical compositions, manufacturers and batch numbers of the main materials used in this study.

Product Name	Type	Chemical composition	Manufacturer	LOT number
Gel Etchant 37,5%	Etch gel	37,5% phosphoric acid	Kerr, Orange, CA, USA	5253847
Optibond FL Prime	One component primer	HEMA, GPDM, MMEP, ethanol, water, initiators	Kerr, Orange, CA, USA	5420027
Optibond FL Adhesive	Bonding agent	Bis-GMA, HEMA, GPDM,barium-aluminum borosilicate glass, disodium hexafluorosilicate, fumed silica	Kerr, Orange, CA, USA	5387796
Tetric Evo Flow A3	Flowable composite	dimethacrylates (38 % wt), barium glass, ytterbium trifluoride, highly dispersed silicon dioxide, mixed oxide and copolymer (62 % wt). Additives, catalysts, stabilizers and pigments (<1 % wt).	Ivoclar Vivadent, Schaan, Liechtenstein	U414555 U18922 U14555 U40296 U40296
Oxyguard	Glycerine gel	Glycerine gel	Kuraray Noritake, Tokyo, Japan	5N0004
Cojet Sand	Blast-Coating Agent 30 µm	Aluminium trioxide particles coated with silica, particle size: 30 µm	3M ESPE, St Paul, MN, USA	
ESPE-sil	Silane coupling agent	Ethyl alcohol, methacryloxypropyl, trimethoxysilane	3M ESPE, St Paul, MN, USA	563857
Monobond Plus	Silane coupling agent	Ethanol, 3-trimetho-xysilsylpropylmetha-crylaat, methacrylated phosphoric acid ester	Ivoclar Vivadent, Schaan, Liechtenstein	T21454
Ceramic etching gel	HF zuur	Hydrofluoride zuur	Ivoclar Vivadent, Schaan, Liechtenstein	T29351
IPS ceramic Neutralizing Powder	Neutralisatie powder	25–50% sodium carbonate, 25–50% calcium carbonate	Ivoclar Vivadent, Schaan, Liechtenstein	T34017
Enamel Plus HFO UD2	Light curing composite		Micerium, Avegno, Italy	2015005256
IPS e.max Press	Lithium disilicate	SiO2, Li2O, K2O, MgO, ZnO, Al2O3, P2O5 and other oxides.	Ivoclar Vivadent, Schaan, Liechtenstein	

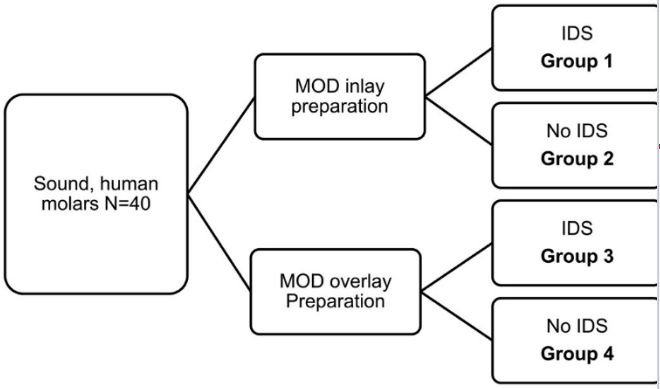

Fig. 1. Flow-chart showing experimental sequen

Leveroy, Nederland), was made for each sample. Standard MOD preparations were made in each tooth (cusps thickness: 3 mm wide, preparation depth: 5 mm measured from the highest cusp) using diamond burs (no. 6847 KR, 8847 KR, 8856, Komet Dental, Lemgo, Germany). For the overlay groups (3 and 4) all cusps were reduced by 2 mm. Preparation was smoothened using rubber polishing points (9609&9620, Komet Dental, Lemgo, Germany). The axial walls were prepared with divergence of <6° to eliminate undercuts. In the IDS groups (1 and 3), IDS was applied immediately after tooth preparation, non-IDS teeth received no further treatment. The IDS procedure involved etching dentin with 37.5% phosphoric acid (Gel Etchant, Kerr, Orange, USA) for 10 s, rinsing for 20 s and subsequent drying for 5 s. Primer (OptiBond FL, Kerr, Orange, CA, USA) was applied for 20 s, followed by suction until dry. Adhesive resin (OptiBond FL, Kerr) was applied for 15 s and polymerized for 20 s using a LED polywave photo-polymerization device (≥1000 mW/cm^2, Bluephase, Ivoclar Vivadent). The IDS surface was covered with a thin layer of flowable composite (Tetric Flow, Ivoclar Vivadent) followed by 40 s of polymerization. After application of glycerin gel (Oxyguard, Kuraray Noritake, Tokyo, Japan), the surface was again polymerized for 40 s. Excess adhesive resin on the enamel outline was removed using diamond burs and the IDS was polished with rubber polishing points (9609&9620, Komet Dental).

2.3. *Impression and fabrication of the restorations*

A final impression (Aquasil Ultra Extra light body and Heavy body, Dentsply, Milford, USA) was made for all specimens and sent to the dental laboratory. To prevent adhesive interaction between the IDS and the provisional restorative material, glycerin gel was applied on the IDS. Provisional restorations were fabricated (Protemp 4, 3M ESPE, St Paul, USA), adjusted using polishing discs (Sof-Lex Contouring and Polishing Disks, 3M ESPE) and luted with temporary cement (Durelon, 3M ESPE). Afterwards, samples were stored in water (20 °C) for another 3 weeks. One dental technician fabricated lithium disilicate (IPS e.max Press, Ivoclar Vivadent) inlays and overlays according to the instructions of the manufacturer. The preparations were scanned, the restorations were digitally designed, milled in wax and then pressed. After finishing they were glazed in an oven (Programat EP5000, Ivoclar Vivadent).

2.4. *Adhesive luting*

The provisional restorations were removed, each tooth was cleaned with pumice and the fit of the ceramic restorations was checked using a probe. Inner surfaces of the ceramic restorations were conditioned using 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar Vivadent) for 20 s, rinsed with water and a neutralizing powder (IPS Ceramic neutralizing powder, Ivoclar Vivadent). The restorations were ultrasonically cleaned (Emag, Valkenswaard, the Netherlands) in distilled water for 5 min. Thereafter the restorations were dried, silanized (Monobond Plus,

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HFO UD2, Micerium) was used to lute the restorations and pressure was applied until fully seated, excess of composite was removed with a probe and microbrushes. The margins of the restoration were covered with glycerin gel and polymerized for 40 s each from buccal, palatal, mesial, distal and occlusal sides (Bluephase, Ivoclar Vivadent, ≥1000 mW/cm^2). Margins were polished using tungsten carbide burs (H390EF, Komet Dental), discs (Sof-lex Contouring and polishing disks, 3M ESPE) and rubber polishing points (9609,9620, Komet Dental).

2.5. *Thermomechanical aging, fracture test and analysis*

All specimens were artificially aged in a chewing simulator (SD Mechatronik CS-4.8 Chewing Simulator, Feldkirchen-Westerham, Germany) using a zirconia ceramic antagonist sphere loaded on the occlusal plane for 1.2×10^6 cycles (1.7 Hz, 50 N). They were simultaneously thermocycled for 8000 cycles (between 5 and 55 °C, dwell time 30 s, transfer time: 5 s). Subsequently, the samples were evaluated on failures, cracks and fractures under magnification (40×, Wild, Heerbrugg, Switzerland) and digital pictures were taken. The specimens were then mounted in the Universal Testing Machine (810 Material Test System, MTS, Eden Prairie, USA) and loaded with an 8 mm steel ball, 45° to the occlusal surface, on the functional cusp at a crosshead speed of 1 mm/min (Fig. 2). The maximum load to failure (N) was recorded.

Failure sites were initially observed using an optical microscope (40x, Wild, Heerbrugg, Switzerland) and classified as follows: Score 1: fracture of enamel; Score 2: fracture of enamel and dentin; Score 3: fracture of the restoration; Score 4: fracture of the restoration and enamel; Score 5: fracture of the restoration, enamel and dentin; Score 6: root fracture. Fractures were analyzed on reparability: fractures above the CEJ were furthermore classified as 'reparable' and those below CEJ extending in the root as 'non-reparable'.

Additionally, representative specimens from each group were sputter-coated with a 3 nm thick layer of gold (80%)/palladium (20%)

Fig. 2. Sample in universal testing machine at 45° for load to fracture test. Force applie

(90 s, 45 mA; Balzers SCD 030, Balzers, Liechtenstein) and analyzed using cold field emission Scanning Electron Microscope (SEM) (LyraTC, Tescan, Brno, Czech Republic).

Data were analyzed using a statistical software package (SPSS 24, SPSS inc., Chicago, USA). Kolmogorov-Smirnov tests were used to test normal distribution of the fracture strength data. As these data were normally distributed ($p > .05$), a two-way ANOVA was applied to analyze possible interactions and effects of the variables on fracture strength results, post hoc custom hypothesis tests were applied to analyze differences between groups. The failure mode and reparability data were analyzed with a Fisher's exact test (assumptions for Chi-square violated).

3. Results

All samples withstood the aging simulation, no visible cracks were found in the tooth or the restoration. Mean fracture loads, standard deviations and other descriptive measures are shown in Table 2. After verifying normality and homogeneity of the data, a two-way ANOVA was conducted to examine the influence of two independent variables (preparation type and mode of dentin conditioning) on the fracture strength. Preparation type included two levels (inlay, onlay) as did mode of dentin conditioning (IDS, no IDS). Both main effects were statistically significant. Teeth restored with an overlay were stronger than those restored with an inlay restoration ($F(1,36) = 15.31$, $p < .001$). Teeth with IDS were stronge
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($F(1,36) = 1.25$, $p = .27$).

The mode of failure (Fig. 3) was analyzed with a Fisher's exact test and gave statistically significant interactions between preparation design and the presence of IDS. Overlays gave statistically significant ($p = .001$) more root fractures than inlays (IDS and non IDS combined). Analyzing inlays, IDS influenced the failure mode statistically significantly ($p = .015$). The absence of IDS gave more extensive failures, whereas the presence of IDS gave a diversity of failures. . Analyzing overlays, there was no statistically significant influence of the presence of IDS on the fracture mode.

Analyzing the reparability (Fig. 4) with a Fisher's exact test indicates that there was a statistically significant influence of the absence of IDS and the preparation design on reparability ($p = .003$): overlays without IDS account for 70% more non-reparable fractures than inlays without IDS. There was no statistically significant difference in reparability between inlay and overlays with IDS ($p = .07$), but overlays tend to fracture in a more non-reparable manner.

In a SEM image of a representative root fracture sample of the overlay with IDS group, the weakest link of the adhesive interface was

Table 2
Fracture load results (Newton) of experimental groups, minimum and maximum and 95% confidence interval. Same superscript letters (a or b) indicate no significant difference between groups.

Group	n	Mean ± SD	Minimum	Maximum	95% confidence interval	
					Lower bound	Upper bound
Inlay + IDS	10	1609,67 ± 418,76^{A}	868,84	2296,71	1310,10	1909,23
Inlay -IDS	10	1115,33 ± 487,47^{B}	530,20	2172,15	766,61	1464,04
Overlay + IDS	10	2010,95 ± 495,74^{A}	1426,19	2889,28	1656,32	2365,58
Overlay -IDS	10	1836,75 ± 405,80^{A}	1103,50	2374,32	1546,46	2127,04

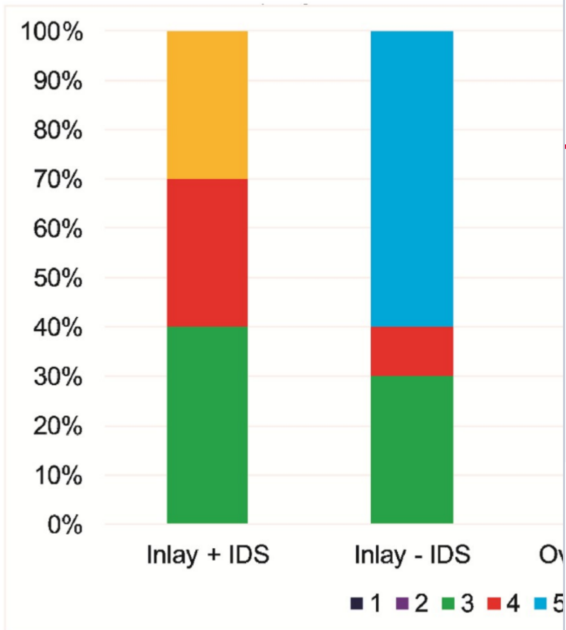

Fig. 3. Frequencies of failure modes after fracture test. Score 1: fracture of the enamel; Sco
Score 4: fracture of the restoration and enamel; Score 5: fracture of the restoration, enamel

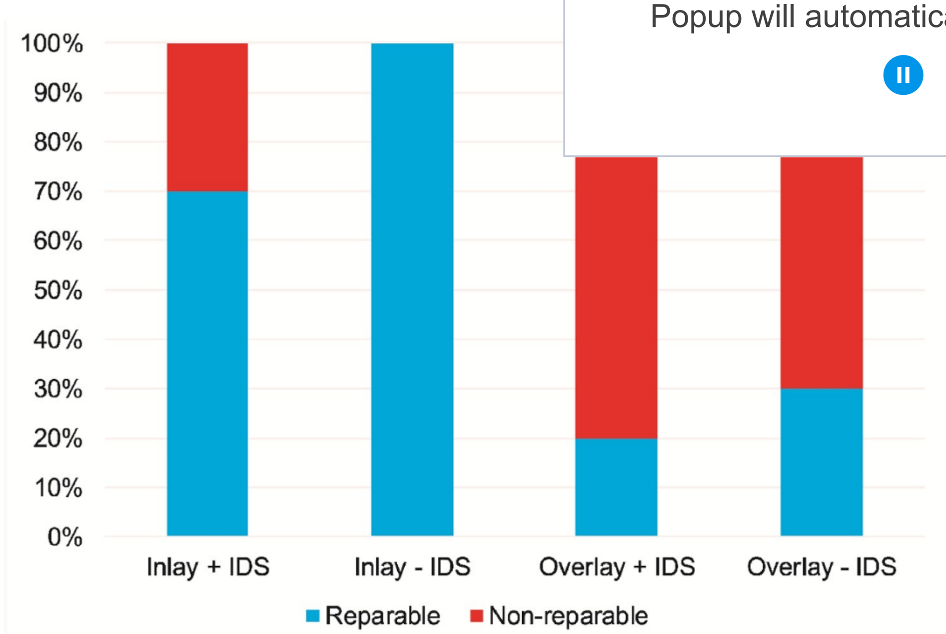

Fig. 4. Frequencies of reparability: reparable and non-reparable failures. Inlay + IDS: 70% reparable; Inlay-IDS: 100% reparable; Overlay + IDS: 20% reparable; Overlay-IDS: 30% reparable.

the dentin-IDS interface as the enamel-composite and composite lithium disilicate interface were still intact (Fig. 5).

4. Discussion

This study tested whether the application of IDS could improve the fracture strength and failure behavior of molars restored with lithium disilicate inlays and overlays after aging. To our knowledge, the application of IDS and its influence on the fracture strength of multiple preparation designs were not previously investigated.

The first hypothesis, stating that there is no statistically significant effect of the preparation design and the application of IDS on fracture strength, could be accepted. Both the application of IDS and the preparation of an overlay resulted in a higher fracture strength, so the null hypotheses are rejected. However, the application of IDS does not interact with the effect of the preparation design on fracture strength (and vice versa). The combination of both IDS and an overlay preparation resulted in the highest fracture strength.

The observed higher fracture strength when IDS was applied, is in consensus with other studies (Qanungo et al., 2016; van den Breemer et al., 2017). Little clinical evidence is available on IDS application in inlays and overlays (van den Breemer et al., 2019). In the 11-year follow-up prospective study (Gresnigt et al., 2019) 384 feldspathic porcelain veneers were evaluated with and without IDS. IDS tend to

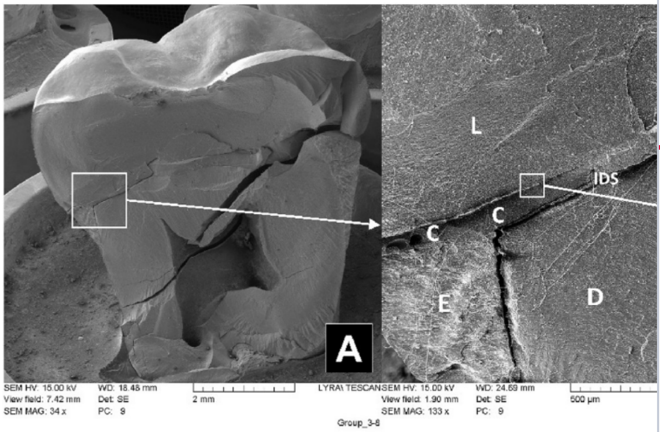

Fig. 5. Corresponding SEM image of representative score 6 failure (Overlay + IDS group).
Immediate Dentin Sealing; **A)** Overview of root fracture (34x); **B)** Detachment of cement
Adhesive interface between composite and lithium disilicate intact (1.33 kx).

support the brittle porcelain veneers, resulting in a higher fracture resistance and increased survival rate. In the present study also, the IDS probably increased the adhesive strength and thereby supported the brittle ceramic restoration, resulting in a higher fracture strength.

Considering failure mode, the second null hypothesis could be rejected as there is a statistically significant difference in failure mode between the groups. The inlays with IDS obtained various failure types, ranging between fracture of the restoration and root fractures. The Fisher exact test showed that overlay groups gave more destructive failures, extending into the root. In other studies, where IDS was not applied the destructive failure of overlays is not found (Saridag et al., 2013; Stappert et al., 2006). Possible explanation for this difference could be the smaller dimensions of the preparations used.

The observed forces that were required to fracture the restorations are higher than the masticatory forces commonly observed in man. That may be the reason that destructive failures of ceramic restorations are not seen in clinical studies with overlays (Beier et al., 2012).

Axial clinical chewing forces are presumed to deviate between 40 and 240 N (Gibbs et al., 1981; Morneburg and Pröschel, 2002). The chewing force applied depends on the type of food that is being processed (Kohyama et al., 2004; Shimada et al., 2012). In addition to axial forces, lateral shear forces also occur in mastication. These forces are less commonly studied, but they are presumed to be lower than the axial forces, and estimated to be around 200 N (Koolstra et al., 1988; Koolstra and van Eijden, 1992). In the present study, while loading under an 45° angle, 95% of the forces to fracture were between 766 N and 2365 N.

There is a statistically significant difference in reparability between the groups. Therefore, the third null hypothesis could be rejected. There was a statistically significant difference in reparability between overlays and inlays without IDS, as overlays gave 70% more non-reparable fractures. When IDS was used a statistically significant difference in reparability was not found, due to the range of failures in the inlay group. Because of the deficiency of clinical studies on IDS, these findings could not be compared. In studies without IDS no difference in reparability is seen between inlays and overlays (Morimoto et al., 2009; Soares et al., 2006). In a clinical situation, fracture and chipping of the restoration are the most frequent cause of failure (Morimoto et al., 2016). A study (Beier et al., 2012) stated that 40% of the failures were due to restoration fracture, fracture of the tooth occurred only in 1 of 547 restorations (3,7% of the failures). Failures in a clinical setting are usually reparable, probably due to different load directions: repeated loading with lower masticatory forces. This laboratory study protocol used load to failure forces. These forces are not often experienced in the oral environment as the forces are more repetitive. The failures in this in vitro study are consequently more destructive and less often reparable in

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5. Conclusions

Within the limitations of this laboratory study, the following could be concluded:

1) The application of IDS and the preparation design both influenced the fracture strength separately. The application of IDS does not interact with the effect of the preparation design on fracture strength.
2) The failure mode of overlays is more destructive and overlays are less often reparable.
3) Both inlays and overlays are strong enough to withstand physiological chewing forces. Since overlays fracture in a more destructive manner, the data suggest that from a biomechanical perspective, inlays with IDS would be the treatment of choice.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Jelte W. Hofsteenge: Formal analysis, Writing - original draft, Visualization. **Femke Hogeveen:** Investigation, Methodology. **Marco S. Cune:** Writing - review & editing, Funding acquisition, Conceptualization. **Marco M.M. Gresnigt:** Resources, Methodology, Supervision, Conceptualization.

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